

# LATE CRETACEOUS AND CENOZOIC VEGETATION IN CHINA, EMPHASIZING THEIR CONNECTIONS WITH NORTH AMERICA<sup>1</sup>

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## ABSTRACT

The close floristic relationship and disjunct occurrence of many plant taxa between eastern Asia and eastern North America has been given special attention by many botanists. Formerly some people thought that this close floristic link was a result of extensive migrations mainly through Beringia, but recently plate tectonic studies demonstrated that the opening of the North Atlantic Ocean was completed as late as the middle Eocene and the land bridge (Beringia) between Asia and North America was not available until the Miocene. Thus the extensive migrations via Beringia did not occur before the Miocene. The present paper reviews the Late Cretaceous and Cenozoic vegetation in China, enumerating plant megafossils of the Late Cretaceous and the Cenozoic Periods so far recorded there. One-half to two-thirds of the Late Cretaceous plants and one-fourth to one-half of the Late Eocene taxa seem similar (or nearly identical) to those of North America, and some plants are cosmopolitan in Laurasia. This indicates that these plants must have migrated directly between eastern Asia and eastern North America via Europe. So far as the megafossils are concerned, after the Eocene only a few Chinese species are common with those of North America. So most of the isolated and disjunct genera of eastern Asia and eastern North America are remnants of ancient plants widely distributed all over the Northern Hemisphere. Eastern Asia and eastern North America at present are two relic temperature centers of the Northern Hemisphere.

The recent flora of China, one of the richest in the world, is a mixture of northern temperate elements and tropical to (northern) subtropical elements. It is characterized by many relic genera and has a close floristic relationship with that of eastern North America.

As to the relicts, in ferns there are *Angiopteris* and *Archangiopteris*; in gymnosperms, *Ginkgo*, *Metasequoia*, *Cephalotaxus*, *Amentotaxus*, *Torreya*, *Taxus*, *Pseudolarix*, *Tsuga*, and *Pseudotsuga*; and in angiosperms, *Magnolia*, *Trochodendron*, *Liriodendron*, *Saururus*, *Illicium*, *Schisandra*, *Nelumbo*, *Euptelea*, *Eucommia*, *Cercidiphyllum*, *Aralia*, *Nyssa*, and *Menispermum*. Most of them are relic genera of the Late Cretaceous.

Fossils like *Ginkgo* and *Angiopteris* have been recorded from southwestern China in the Late Triassic (Hsü et al., 1974); *Torreya* and *Taxus* were described from the Jurassic of Europe by Florin (1958); *Metasequoia* was quite abundant in the Late Cretaceous and the Late Eocene of northeastern China. *Metasequoia*, *Glyptostrobus*, *Cryptomeria*, *Cunninghamia*, *Cephalotax-*

*us*, and *Amentotaxus* were widely distributed in Eurasia and North America during the Late Cretaceous (Florin, 1963). Now some primitive families of angiosperms, such as, Magnoliaceae, Calycanthaceae, Schisandraceae, Nyssaceae, Staphyleaceae, Platanaceae, Saururaceae, and Illiciaceae are widely distributed both in South, East, Central, and southwestern China on the one hand and eastern North America on the other. The genera *Fagus*, *Lithocarpus*, *Castanea*, *Quercus*, *Trigonobalanus*, *Diphylleia*, *Lindera*, *Aspilbe*, *Itea*, *Hamamelis*, *Cladrastis*, *Carya*, *Buckleya*, *Stylophorum*, *Penthorum*, *Decumaria*, *Gymnocladus*, *Ascyrum*, *Halesia*, *Chionanthus*, *Campsis*, and *Catalpa* are examples of the distribution pattern between these two regions (Li, 1971). Others like *Wisteria*, *Apios*, *Pachysandra*, *Glaucidium*, *Gordonia*, *Nyssa*, *Chionanthus* s.s., *Stewartia*, *Panax*, *Pieris*, *Lyonia*, *Epigaea*, *Shortia*, *Gelsemium*, *Veronicastrum*, *Phryma*, *Mitchella*, *Triostreum*, *Zizania*, *Diarrhena*, *Croomia*, *Symplocarpus*, *Tipularia*, *Celastrus*, and *Diospyros* are also disjunct between eastern Asia and eastern North America (Li, 1971, 1972).

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These genera, formerly believed to number about 80, are now increased to more than 120, among which 112 are recorded from China (Wu, 1984).

To these facts special attention has been paid by many phytogeographers since the time of Asa Gray (1846) and later on by Good (1947), Li (1971, 1972), Wu (1984), and many others. The cause of this disjunction has been demonstrated by various authors from paleobotanical, ecological, and floristic points of view. Li (1971: 404–405) thought that “the present isolated and disjunct floras of eastern Asia and eastern North America appear to be the remnants of a great mesophytic forest that extended over all the northern hemisphere and reached the arctic regions in the Tertiary. Geological changes, including mountain elevation, submergence, climatic variations, glaciations, etc., have destroyed and changed the floras of many lands so that this mesophytic forest of the Tertiary in the northern hemisphere survives in eastern Asia and eastern North America, with only relicts scattered in southeastern Europe, western Asia, and western North America.” But Li did not mention the route of migration. However, Takhtajan (1969, p. 175) wrote that during the Late Cretaceous there existed extensive migrations and close links between Eurasia and North America, both by the North Atlantic route (across the landbridge that included what is now Greenland and Iceland) and by the North Pacific route (through Beringia). He further suggested that the link through Beringia was a particularly strong one and served as a bridge joining North America directly to eastern Asia. Anyway, judged from current paleomagnetic investigations, there was no land bridge in the Bering area available between Asia and North America before the Miocene.

In the present paper I review the late Cretaceous and Cenozoic history of the vegetation of China, trace the successional stages of the past floras in China, analyze the possible causes for survival of such a large number of relicts in China, and discuss the relationship of the Chinese past floras with those of eastern North America, particularly emphasizing the migration routes between eastern Asia and North America.

#### GEOLOGY AND PALEOGEOGRAPHY

According to the paleogeomagnetic data given by Dietz and Holden (1970) during the late Paleozoic and the early Mesozoic, North America, Greenland, and Eurasia were united together as

a supercontinent, Laurasia. Even up to the start of the Tertiary, northern North America remained firmly attached to Eurasia, with Greenland sandwiched between them. Van der Linden (1975) proposed that the Labrador Sea in the North Atlantic opened in two stages, the first in the late Jurassic–early Cretaceous (about 138 to 110 million years ago) and the second in the early Tertiary (about 60 to 47 million years ago). By the Late Cretaceous, southern Europe was situated at a lower latitude somewhere about 15 to 30°N, the eastern United States at 19 to 20°N, and the Bering area at a higher latitude at 75°N (Dietz & Holden, 1970).

Passing on to the start of middle Eocene (about 49 million years ago) North America and Greenland began to separate from Eurasia and the North Atlantic became a major ocean (Raven & Axelrod, 1974; Schuster, 1976). Europe had drifted some degrees northward (Dietz & Holden, 1970).

According to these authors, India was cut free from east Africa and initiated its migration northward at the beginning of the Jurassic (about 180 million years ago). McElhinny (1970) presented data indicating that the initial rifting took place only in the Mid-Cretaceous, about 100 million years ago. So it is safe to say that the Indian block migration started only after the middle Cretaceous. This plate, drifting northward some 5,000 km at an average rate of 7.5 cm per year, with rates varying from 16 cm per year to less than 6 cm per year, reached Eurasia and joined up with northern Xizang (Tibet) by the middle Eocene, about 40 to 45 million years ago, to become a subcontinent of Asia (Hsü, 1978). The suture of the Indian plate and the Eurasian plate lies along the Yarlung-Zambo valleys. So the southern part of Xizang is actually a part of Gondwanaland.

At the same time, the Himalayan orogenic impulses affected by the collision of the Indian plate and the Eurasian plate caused the uplift of the Himalayas and withdrawal of the Tethys, the Obé Sea in Central Asia, and the Kachi Bay in western Sinjiang, during the time of Oligocene (about 25 to 40 million years ago).

By the estimate of Deffeyes (1973), the tectonic movement of the Pacific plate was northwest until 60 million years ago. Until 25 million years ago, the plate moved directly northward. Up to the present it moved 1,500 km at an average rate of 25 cm per year. Today, for certain plates, migration rates of 16 cm per year are generally ac-



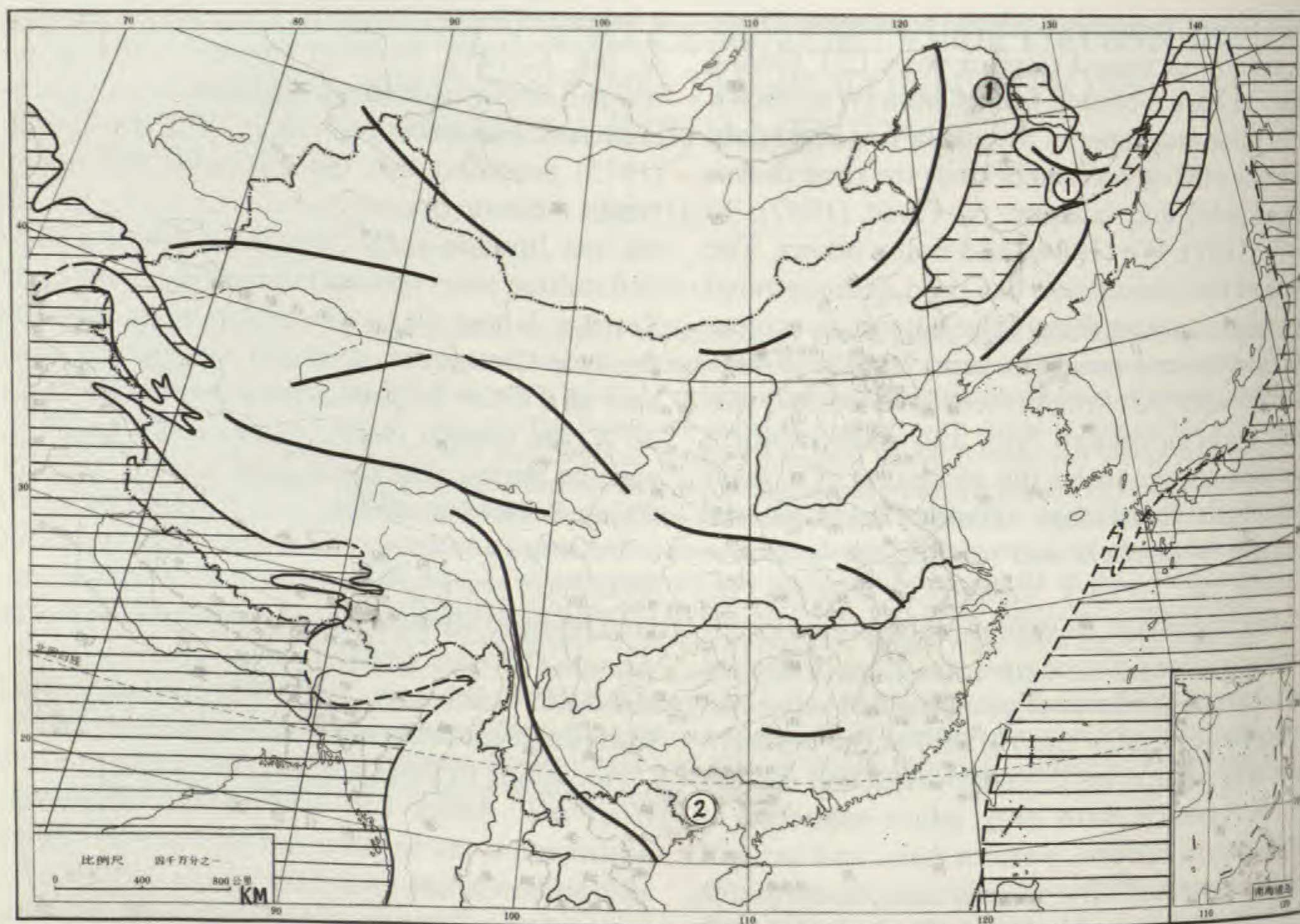


FIGURE 1. Late Cretaceous fossil localities of China: 1. Northern China; 2. Southern China. Heavy curves represent mountain ranges.

cepted as accurate, at least for portions of the time intervals. This suggests that from the middle Paleocene to present, the Pacific plate has moved  $9^{\circ}$  northward. So it is reasonable to estimate that from the late Cretaceous to the present, if the map given by Dietz and Holden (1970) is correct, Asia was relatively stable and would have moved about  $10$  to  $13^{\circ}$  northward.

By the late Cretaceous the northern side of China was bordered by Siberia and Outer Mongolia (Fig. 1). Ancient land of Xizang and Talimu lay on the northern coast of the Tethys. On the Pacific coast, the Sea of Japan, the Yellow Sea, the East China Sea, and the South China Sea were not yet covered by water. In western China, a series of mountain ranges, the Altai, the Tianshan, the Kunlun, the Altyn Tag, and the Qilianshan, running from west to east, already existed (Fig. 1). The watershed of the Salween-Mekong-Yangtze Rivers (the Hengduan Shan Ranges) had already formed. In the north, the Ying Shan (Inshan), the Taixinanling (Great Khingan), and the Xianxianling (Small Khingan) Mountains began to rise. In the south lay the Qinling (Tsinling), the Dabie Shan, and the Nan-

ling Mts. Some more mountains had been folded in Jilin (Kirin) and Liaoning before Tertiary due to the effect of the collision of the Pacific and the Indian plates against the Eurasian plate. The Xizang, Yunnan-Quizhou, North China, and North Shansi Table-Lands began to form. Among the mountains of northeastern provinces a large lake, Songhua Lake, appeared. Judged from the presence of gypsum and salt in the deposits and formation of red beds of southern China, a broad dry zone persisted there from the Mid-Jurassic up to the Oligocene, ranging from Central Asia, Yunnan to East China, south of the Qinling Ranges.

During the early Tertiary, due to the movement of the Indian plate against the Eurasian plate, all the mountain ranges in western China gradually arose. At the same time, the Xizang and the Yunnan-Quizhou plateaus were formed. Then, the Shaanxi-Shanxi and the Jiangnan plateaus came into existence due to the collision of the Pacific plate against the Eurasian plate. By the same process many mountains were folded in Zhejiang (Chekiang), Fujian (Fukien), and Guangdong (Kwangtung) of East and South China.



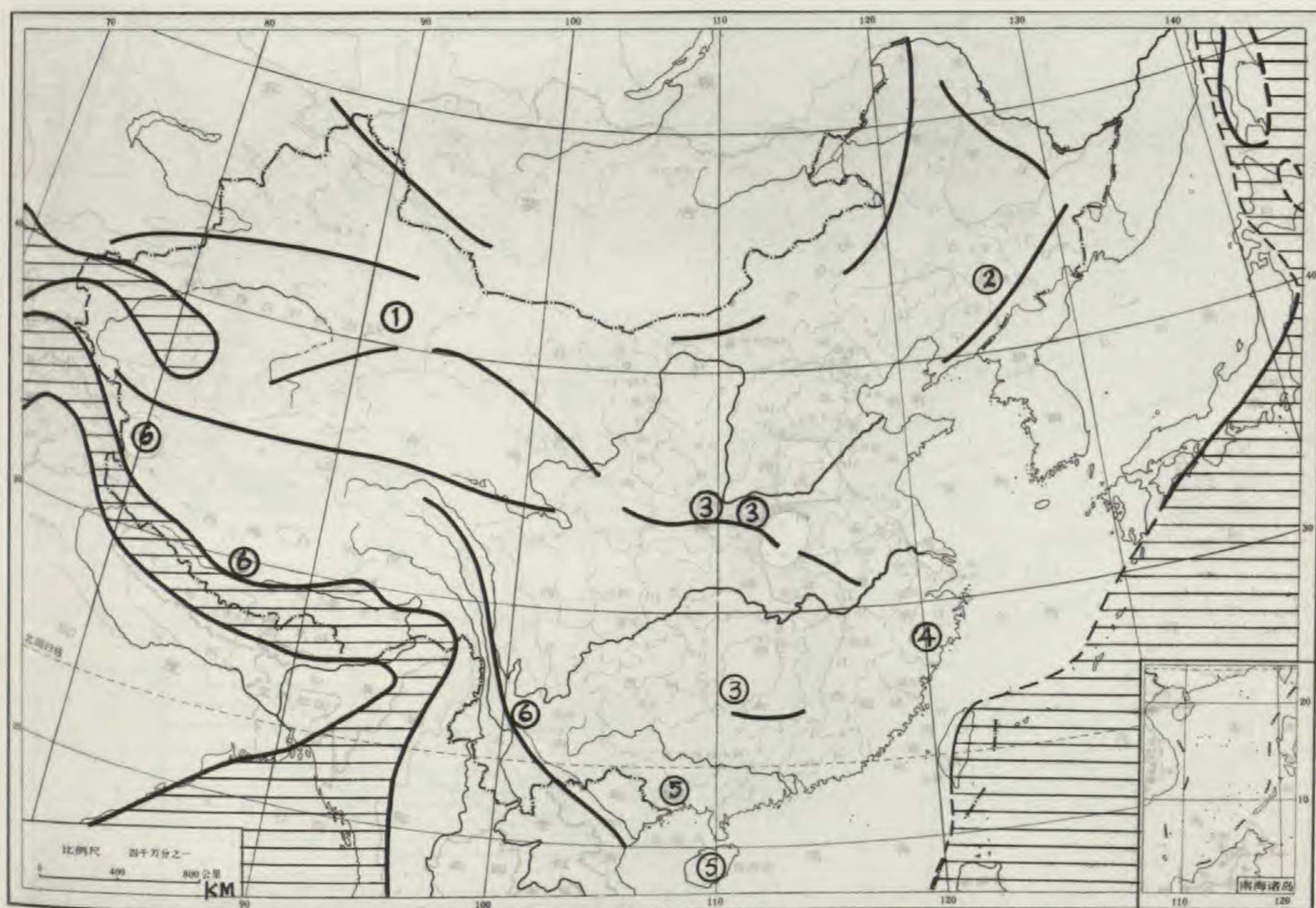


FIGURE 2. Paleogene vegetation of China: 1. Dry climate flora of northwestern China; 2. Warm temperate to subtropical deciduous and coniferous forests of northeastern and North China; 3. Dry climate subtropical floras of Central China; 4. Subtropical deciduous and evergreen forests with coniferous forests of East China; 5. Subtropical deciduous and evergreen forests associated with coniferous forests and tropical mangrove vegetation of South China; 6. Subtropical vegetation of Yunnan and Xizang.

Rising of the ocean water level led to an eastern sea coast closer to that of the present. But the coast range geosyncline extended along the Pacific margin of South and East China from Guangdong to Fujian, so the South China Bay was formed and Taiwan became submerged. In the meantime a series of large lakes appeared in the regions south of Beijing, north of Shanghai, and south of Dabie Mts. (Fig. 2).

During the late Tertiary, the topography of China became closer to that of the present. The Sea of Japan, the Yellow Sea, the East Sea, and the South China Sea began to appear. Taiwan and Hainan were uplifted to become islands. Up to the late Pliocene, many mountains of West China arose. The Himalayas and the Tanggula Ranges upheaved over 3,000 m in elevation, and the Qinghai-Xizang Plateau became higher than 2,000 m above the sea-level. The Talimu (Tarim) Basin, south of the Tianshan Ranges of Xinjiang province and the Quidam (Tsaidam) Basin of Qinghai province (Kokonor) turned into dry re-

gions. Later on these dry regions extended further eastward up to the west part of Gansu (Kansu). Finally, the Talimu Basin became desert and some parts of Qinghai and Gansu gradually changed to semidesert (Fig. 3).

By the Quaternary, the topography of China was almost identical to that of the present but with slight differences. The Gulf of Pohai appeared in North China during the interglacial periods (Fig. 4). Hainan Island was once connected with the continent, but later a strait formed between them due to local subsidence of land. In northeastern China, the Taixinanling and the Xiaoxinanling Mountains were elevated, and in North China Taihangshan and the Inner Mongolian and the Loess Plateaus were raised. By that time the Himalayas and the Xizang Plateau were rapidly uplifted. The Xizang Plateau was only about 3,000 m in elevation in the early Pleistocene, but it reached 4,000 m in the late Pleistocene and in the Holocene went up to 4,500 to 5,500 m (Xu, 1981). At the same time, the



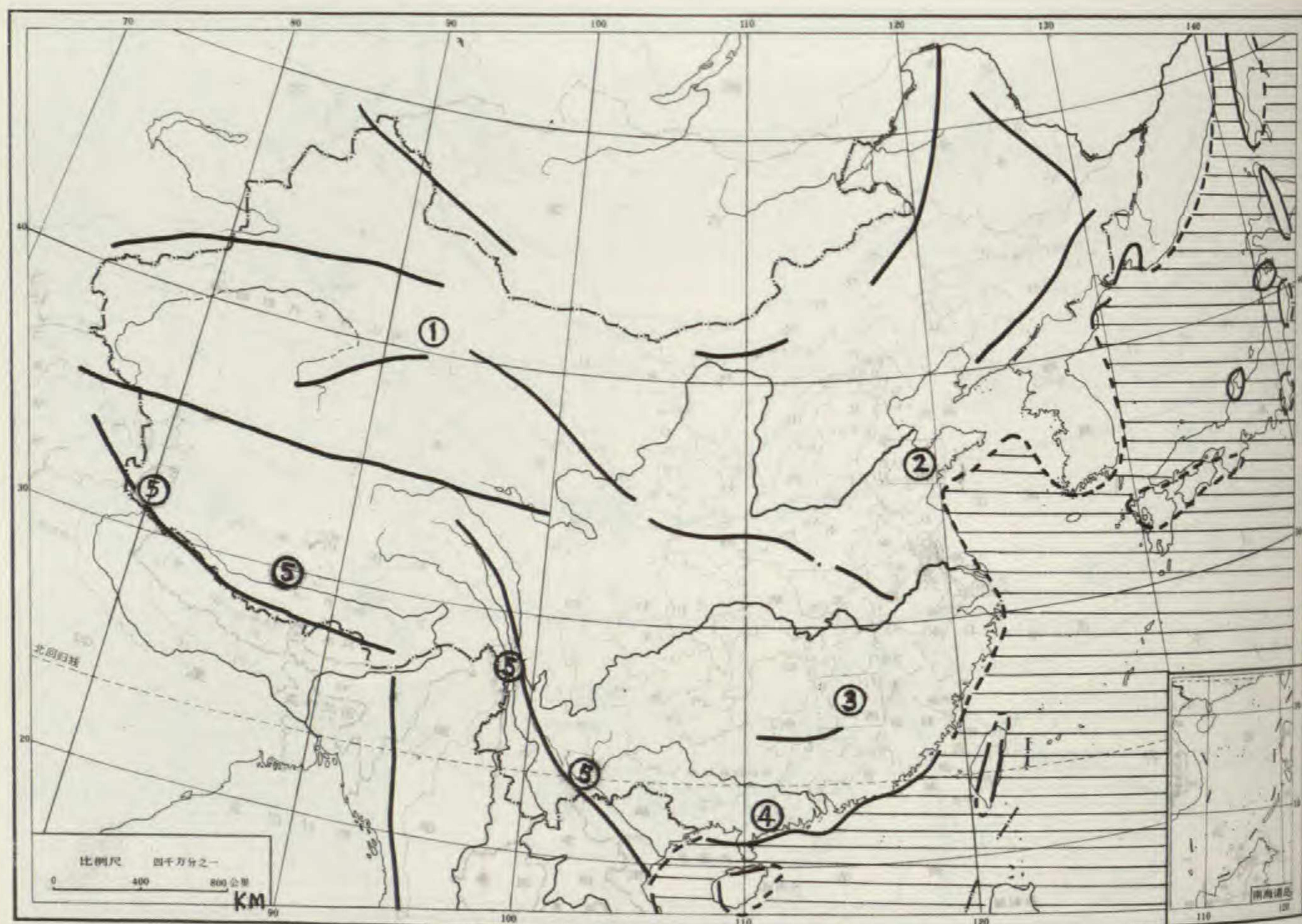


FIGURE 3. Neogene vegetation of China: 1. Temperate forests and grasslands to semidesert-desert floras of northwestern China; 2. Temperate to subtropical deciduous forests and grasslands of northeastern and North China; 3. Subtropical deciduous and evergreen forests of Central and East China; 4. Subtropical evergreen forests and tropical mangrove vegetation of South China; 5. Subtropical deciduous and evergreen forests of Yunnan and Xizang.

mountains of North China were further uplifted. Inner Mongolia, Shanxi, Shānxi, and a part of Gansu became table-lands. Loess blanketed much of this part of the country. Judging from the palynological data, I suggest that the Qinling may have reached its present altitude after the early Pleistocene. The desert of northwestern China further extended eastward. As a result of this development, western portions of Inner Mongolia and Heilongjiang became desert or semidesert.

It is well known that the Quaternary had several ice-ages. The poles of the earth were entirely covered by ice caps and glaciers occurred wherever the altitude was high enough. During the Pleistocene the ice caps increased very much in size and area, and the glaciers not only became more numerous, but also extended to cover all of Canada, the northeastern (not the southeastern) part of the United States, and most parts of western and central Europe. According to the estimate of Antevs (1928), by the time the ice

sheets reached their maximum extent and thickness, the sea level would have been lowered to 100 m below the present level. Various estimates made from the present depths of shore deposits, coral reefs, etc. give a minimum figure of about 60 m (Brooks, 1950). In this way many shallow seas around the world would have disappeared. So it is reasonable to assume that all the shallow seas along the Pacific coast of China were land at least several times during Pleistocene. In addition, some of the southern Japanese islands were connected with each other and with the main continent of Asia. Taiwan and Hainan were connected with the mainland of China. Southeastern Asia and the Malaysian Peninsula were connected with Borneo, the Philippine Islands, Celebes, Sumatra, and Java. Moreover, there were also some land bridges between the Indonesian islands, the Moluccas, New Guinea, and Australia.

At present, the western Aleutians are bordered on both the north and the south by deep ocean.



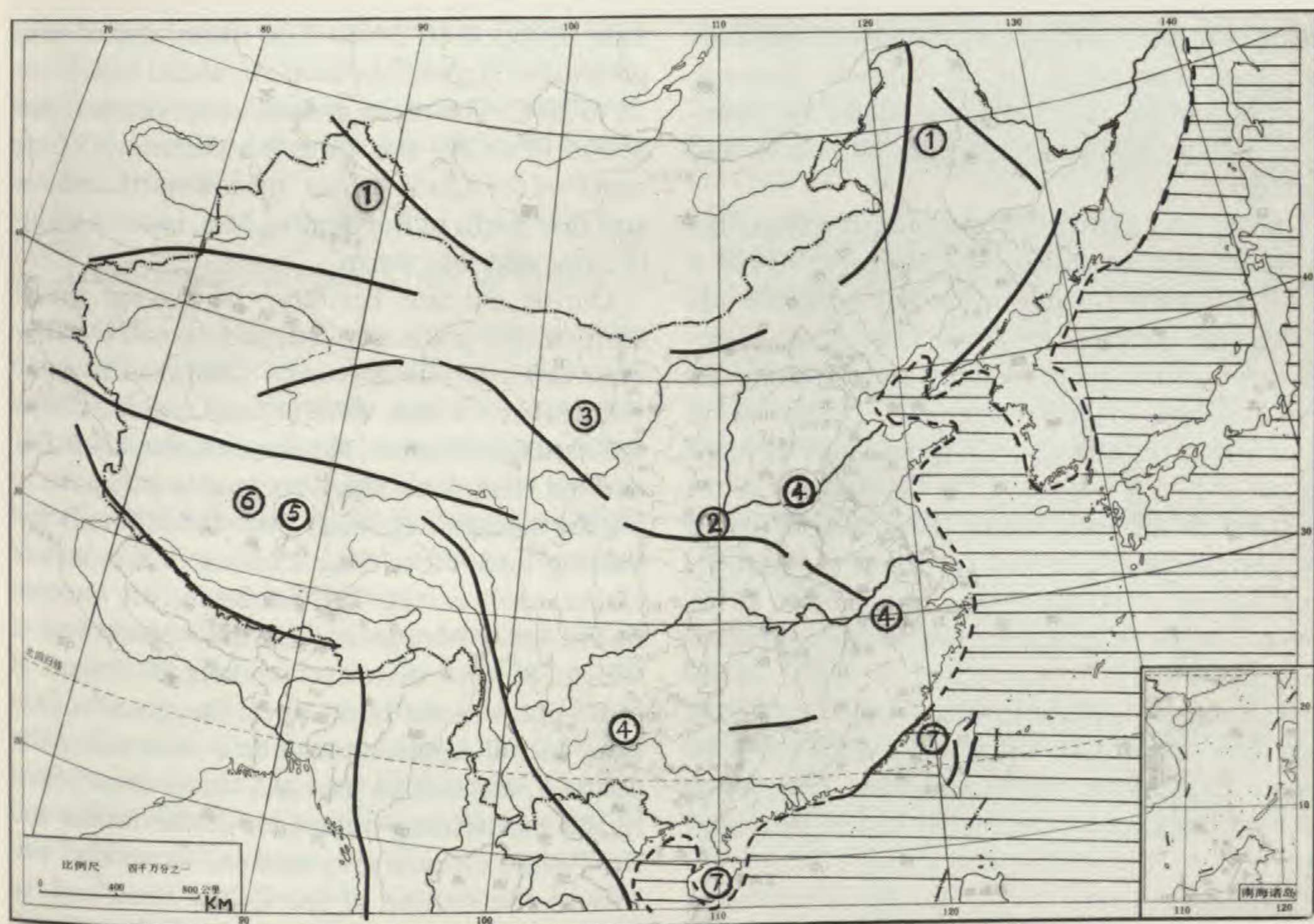


FIGURE 4. Changes in Quaternary vegetation of China: 1. Appearance of taiga; 2. Migration southward of temperate deciduous forests; 3. Expansion of dry climate flora in northwestern China; 4. Changes in vegetation due to oscillation of temperature; 5. Vegetational changes in Xizang; 6. Certain evolutionary changes accelerated; 7. Migration of plants via temporary land connections.

but the Bering Sea and the north side of the Aleutians and the Alaska Peninsula are bordered only by a shallow sea 27 to 95 m deep. So this portion of the Bering region would have become a very wide land mass favorable for plant migration between eastern Siberia and Alaska. However, during the interglacial periods, as the glacial sheets retreated and a large mass of the glaciers melted, sea level would have returned to the level of the interglacial periods, more or less like that of the present. Plant migration would have been temporarily blocked by sea between them.

#### CLIMATE

It is generally accepted that Cretaceous temperature was higher than that of the present. According to the estimate of Schwarbach (1963), the average annual temperature of the Late Jurassic in the world ranged between 25°C and 28°C. In the Early Cretaceous, the maximum temperature was 24°C, but in the Cenomanian (about 96 to 103 million years ago), sea temperature

was reduced to 16°C. In the Coniacian-Santonian (about 80 to 90 million years ago), sea temperature rose to 22°C, but by the end of the late Cretaceous it declined again to 20°C. Saito and van Donk (1974) determined the isotopic temperature of bottom-water at the same sites around 14 to 15°C for Campanian (about 70 to 78 million years ago) and early Maastrichtian (about 68 to 70 million years ago), about 12°C higher than that of the present. It suggests a mild temperate climate in polar regions with surface-water around 14 to 15°C. Sea surface temperature declined over 2°C from the Middle to the Late Maastrichtian (about 66 to 68 million years ago), and further declined by 1.5°C from the late Maastrichtian to the early Paleocene (about 64 million years ago).

Gordon (1973) suggested that "Cretaceous oceanic circulation was an equatorial current system flowing through the Tethys and across the northwestern Pacific Ocean in a circumglobal band of warm water with its own characteristic fauna." Western winds probably existed at high



latitudes in the Northern Hemisphere, and current gyres existed as in the present. Drewry, Ramsay, and Smith (1974) claimed that the trade-wind system existed during the Mesozoic and Tertiary.

During the Late Cretaceous, China mainly lay in the tropical to subtropical region of about 5 to 40°N, but the northernmost part probably was in the warm temperate zone. Due to plate tectonic movement of the Pacific plate and the Indian plate against the Eurasian plate, China would have drifted some 10 to 13° northward, as mentioned above, from the Late Cretaceous to the Quaternary. Accompanying the rapid shifting of geographical position and uplift and the appearance of a series of great mountain ranges in the western part of China, the climate changed gradually from warm to cooler; so the basic development of the climate in China may be divided into three stages: Late Cretaceous to Eocene, Oligocene to Pliocene, and Quaternary. The annual average temperature from the Late Cretaceous to the present has decreased about 12°C.

During the Late Cretaceous, the warm Pacific current bathed the eastern shore of Asia, steadily drifting poleward with the warm Indian Ocean drifting in a northwesterly direction around the northern shore of the Tethys. Accompanied by warm winds these currents produced the warm climate in China and caused abundant rainfall in the northeastern part and less in the southern and western parts. There still was a great expansion of dry belt from southwestern, Central, South to East China. Summarizing, in China the climate of the Late Cretaceous was basically subtropical.

By Eocene time, the warm Pacific and Indian ocean currents were still present. Frakes and Kemp (1972) determined from oxygen isotopes that the mean annual temperature of the warm Pacific Ocean current along the eastern coast was 33°C and that of the warm Indian Ocean current 37°C. The mean annual temperature around Beijing was calculated to be slightly more than 20°C. At the same time, the climatic conditions in other areas were similar to those of the Late Cretaceous. Some large lakes appeared south of Beijing and southern Liaoning, so the climate of these parts was probably wetter than earlier.

In the Oligocene, the mean annual temperature of the Pacific Ocean current along the coast of southern China declined to 18°C, although the direction of the current was the same as before. The temperature of the Indian Ocean current

then dropped to 34°C. The mean annual temperature of Beijing has been calculated to be about 15 to 20°C. The mean annual temperature is now about 15°C. By this time the climate of China south of the Qinling Mts. turned warm and wet and that north of the Qinling Mts. became slightly drier and less warm.

During the late Tertiary, the average annual temperature gradually dropped 7 to 10°C. Many mountains of southwestern China, such as the Himalayas—which were at least about 2,500 to 3,000 m in elevation, the Kunlun, the Altyn Tag, and the Hengduan Shan, became barriers, blocking the monsoonal winds from the Indian Ocean passing into Tibet. The climate of this part of China, such as the Talimu Basin, the Quidam Basin, Inner Mongolia, and the western part of Gansu, became drier and warmer. As a result of rapid uplift of the Himalayas, the climate of Xizang and Qinghai became drier and colder. By contrast, the eastern part of China was subjected to the moderating influences of the Indian and the Pacific Oceans and became warm and wet. Due to the barrier of the Qilian Shan and the Qinling Mts. across the middle part of China, running from west to east, cold air masses from Siberia were blocked and the climate of southern China became warm and wet. According to the results of recent investigations on the geology of China during the Pleistocene, there is no reliable evidence of glaciation on the mountains in the eastern part of China, except the Taibei Shan of the Qinling Ranges. But the temperature of northeastern China became cooler and slightly drier than before and was temperate in nature. There was a marked drop of temperature to the Quaternary. In comparing it with that of the Late Cretaceous, the average annual temperature would have declined 14 to 24°C. Judging from the plant fossils found at Weinan (109.5°E, 33.3°N) in Shānsi Province and Panxian (104.7°E, 25.8°N) in Guizhou Province, the difference in temperature between the Wisconsin Glacial Period and the present in the eastern part of China is around 8°C lower.

As the Quaternary is the most active period of the upheaval of the Himalayas and the Xizang Plateau, the climate of Xizang Plateau during the interglacial periods of early and middle Pleistocene was relatively moderate. But up to the late Pleistocene and Holocene the climate became dry and very cold. Other parts of western China also became dry and cold. However, the temperature and amount of precipitation of the



southernmost part of southwestern China and the coastal region of South China, Guangdong, and Guangxi, the Hainan Island, the southern part of Taiwan and the islands of South China Sea were tropical.

#### LATE CRETACEOUS VEGETATION IN CHINA

During the Late Cretaceous and Cenozoic, the Chinese floras were differentiated into two major floristic zones, the northern and the southern. The demarcation was clearly controlled by a chain of mountain ranges, running from west to east, that is, the Kunlun, the Altyn Tag, the Qilian Shan, the Qinling, and the Dabie Shan. The vegetation as a whole was subtropical.

According to Berry (1937) and Axelrod (1952), by the middle Cretaceous the floras of the world were already differentiated into Arcto-Cretaceous, Tropical Cretaceous, and Antarcto-Cretaceous provinces. The Late Cretaceous was further differentiated into two distinct floras—Boreal and Tethyan (Takhtajan, 1969)—corresponding to the Arcto- and Tropical Cretaceous Floras. The Boreal-Cretaceous flora was temperate in nature, consisting chiefly of mesophyllous deciduous trees and shrubs together with ginkgoes, conifers, and ferns. This flora was widely distributed in the northern part of North America, the Arctic, Greenland, North, Central and northeastern Europe, Kazakhstan, Siberia, the Far East of the U.S.S.R., Korea, and Japan. The Tethyan-Cretaceous flora was subtropical in nature, consisting mainly of evergreen trees and shrubs, with some deciduous, comparatively narrow-leaved forms. In this flora, Lauraceae, Aquifoliaceae, evergreen Fagaceae, and palms were characteristic, as well as Myrtaceae and Sapotaceae. It was widely distributed in the southern part of North America, southern England, southern Europe, the Baltic, the Caucasus, the southern part of the Caspian Sea, Turkman, Central Asia and the main part of China, and Outer Mongolia. In the southern part of this region, a broad, seasonally dry zone extended from Spain and north Africa, through West and Central Asia to eastern China and northern Indo-China, judged from lithological data. South of the subtropical Tethyan-Cretaceous flora lay the Paleotropical Cretaceous flora. Fossils known from Nigeria, Egypt, Syria, Iraq, and Iran indicate the existence of a tropical flora of the Malaysian type. Remains of mangrove vegetation flourished on the northern shores and islands of the Tethys (Takhtajan, 1969).

#### LATE CRETACEOUS FLORA OF NORTHERN CHINA

Late Cretaceous fossils of northeastern China have been recorded from the Hunchun Group in the Hunchun Basin of Jilin and the Sungari Series of Wuyun of Heilongjiang (Fig. 1:1).

Both megafossils and microfossils were mainly of ligneous plants, though sporopollen assemblages included ferns, gymnosperms, and herbaceous plants.

Flora of the lower part of the Hunchun Group and Hunchun Basin (130°E, 42.8°N) of Jilin, of Turonian to Senonian age (95 to 67 million years ago) represents a mesophyllous deciduous forest characteristic of a warm-temperate, humid climate. In this flora the conifers *Glyptostrobus europaeus* (Brongn.) Heer and *Metasequoia cuneata* (Newb.) Chaney are very abundant. Angiosperms include *Populites* cf. *litigosus* (Heer) Lesq., *Juglandites poliophyllus* G. et L., *Trochodendroides vasilenkoi* Iljin et Rom., *Protophyllum multinervis* Lesq., *P. haydenii* Lesq., *P. spp.*, and *Leguminosites* (Guo & Li, 1929).

A similar flora of the Late Cretaceous from Wuyun (129.8°E, 49.11°N) in Heilongjiang flourished in a warm temperate to subtropical humid climate and is under investigation by Tao of our laboratory. In this flora *Osmunda greenlandica* (Heer) Brown and the conifers *Metasequoia* and *Sequoia* were predominant, associated with a few specimens of *Thuja cretacea* (Heer) Newberry. The angiosperms include *Protophyllum* cf. *microphyllum* G. et L., *Pseudoprotophyllum* cf. *dentatum* Hollick, *Betula prisca* Ett., *Alnus*, *Populus carnea* (Newberry) Bell, *Ziziphus phosporia* Krysh., *Mahonia* cf. *furnaria* Brown, *Menispermites borealis* Heer, *M. obtusiloba* Lesq., *M. kuliensis* Tanai, *Ampelopsis acerifolia* (Newberry) Brown, *Debeya tikhonovichii* (Krysh.) Krassilov, *Trochodendroides arctica* (Heer) Berry, *Tetracentron*, *Sorbaria*, *Tiliaephyllum* cf. *tsagajanicum* Kapacnorb., *Viburnum cupanioides* (Newberry) Brown, *V. antiquum* (Newberry) Hollick, *V. asperum* Newberry, *Bauhinia*, *Pterospermites auriculaecordatus* Hollick, *Cissus marginata* (Lesq.) Brown, *Rhus* cf. *turcomanica* (Krysh.) Kor., and *Cyclocarya*.

These fossils lived on the shore of ancient Songhua Lake. They contributed to a mesophyllous deciduous forest, with a few evergreen plants, including *Mahonia* in the forests. At present, *Bauhinia*, *Pterospermum*, *Rhus*, and *Cissus* occur in tropical-subtropical regions.

Judged from the fossils, the Late Cretaceous



flora of northeastern China belonged to the Boreal Cretaceous Flora. It contained a great many temperate taxa, such as *Alnus*, *Betula*, *Corylus*, *Populus*, *Salix*, *Tilia*, and *Zizyphus*, and a few warm temperate to subtropical ones, notably *Mahonia*, *Glyptostrobus*, *Metasequoia*, *Sequoia*, *Platanus*, *Tetracentron*, *Cyclocarya*, *Myrica*, *Nymphaea*, and *Trochodendroides*. The warm temperate to subtropical elements, such as *Ampelopsis*, *Viburnum*, *Sorbaria*, *Rhus*, *Cercidiphyllum*, and *Schisandra*, are quite abundant. Moreover, tropical elements, such as *Bauhinia*, *Cissus*, *Pterospermites*, *Dombeya*, *Dombeyopsis*, and *Grewiopsis*, were associated with the ancient taxa *Protophyllum*, *Pseudophyllum*, and *Dryophyllum*.

Altogether about 40 species have so far been recorded. Twelve of them, *Osmunda greenlandica*, *Glyptostrobus europaeus*, *Thuja cretacea*, *Trochodendroides arctica*, *T. vasilenkoi*, *Menispermities borealis*, *Betula prisca*, *Populites* cf. *litigiosus*, *Debeya tikhonovichii*, *Zizyphus phosphoria*, *Tiliaephyllum* cf. *tsagajanicum*, and *Rhus* cf. *turcomanisa* seem similar to or nearly identical with European, Central Asia, and Siberian Cretaceous plants. Eighteen of them, *Osmunda greenlandica*, *Thuja cretacea*, *Metasequoia cuneata*, *Trochodendroides arctica*, *Cercidiphyllum arcticum*, *Protophyllum multinervis*, *P. haydenii*, *Populites* cf. *litigiosus*, *Menispermities obtusiloba*, *Ampelopsis acerifolia*, *Pterospermities auriculaecordatus*, *Pseudoprotophyllum* cf. *dentatum*, *Viburnum antiquum*, *V. cupanioides*, *V. asperum*, *Cissus marginata*, *Populus carneosa*, and *Mahonia* cf. *furnaria* seem similar to the North American Cretaceous plants.

#### LATE CRETACEOUS FLORA OF SOUTHERN CHINA

Turning to southern China, fossils of *Brachyphyllum rhombiomaniform* Kuo, *Cinnamomum hesperium* Knowlton, *C. newberryi* Berry, *Nectandra prolifica* Berry and *N. guangxiensis* Kuo have been recorded from the Boli Formation of Cenomanian age in the Yongning of Guanxi (Guo, 1979) (Fig. 1:2).

Palynological data show that the flora of the late Early Cretaceous to Cenomanian in Jiangsu and Zheijiang was dominated by *Classopollis* (pollen of *Brachyphyllum* and *Pagiophyllum*), *Ephedra*, *Quercus*, *Schizaeaceae*, and *Ulmaceae*. During this period pinaceous pollen was less common (Wang et al., 1979; Song et al., 1981).

These plants indicate that a dry-climate flora flourished in this subtropical region. Of the species noted above, similar fossils have been recorded in North America, such as *Cinnamomum hesperium*, *C. newberryi*, and *Nectandra prolifica*.

Clearly, the Late Cretaceous flora of southern China was part of the Tethyan-Cretaceous flora.

#### PALEOGENE VEGETATION IN CHINA

The Chinese Tertiary flora can also be basically divided into two zones, demarcated by the same mountain ranges as those of the Late Cretaceous. The northern Paleogene floras were further differentiated into two floras and those in the south into three. These were controlled by geographical and climatic factors. At that time, China was still in a lower latitude, under a subtropical climate.

The northern Paleogene flora was composed mainly of deciduous plants, such as *Carpinus*, *Alnus*, associated with some evergreen species, such as *Quercus*, *Dryophyllum*, and conifers *Sequoia*, *Metasequoia*, *Glyptostrobus*, *Taxodium*, and *Torreya*.

The southern Paleogene flora, which was characterized by typical subtropical taxa, consisted mainly of evergreen trees and shrubs. The herbaceous ground cover was chiefly of drought resistant plants, such as *Ephedra* and *Schizaea*. In most cases the leading role in the forests was played by numerous Lauraceae, such as *Cinnamomum*, *Laurus*, and evergreen Fagaceae, such as *Quercus* (including *Cyclobalanopsis*), *Castanopsis*, *Lithocarpus*, and palms.

#### DRY CLIMATE FLORA OF NORTHWESTERN CHINA

This flora developed in Xinjiang, Qinghai, and western Gansu at the beginning of Paleogene, but later extended to western Inner Mongolia. A grassland vegetation occupied the plain at the beginning but gradually became semidesert (Fig. 2:1).

According to palynological records, by the Oligocene some *Abies* and *Picea* forests with *Tsuga* were flourishing in the high hills on the northern side of the Zhungaer Basin, as were *Cedrus* forests in the lower latitudes. Deciduous forests were composed of *Betula*, *Tilia*, *Acer*, *Quercus*, *Carpinus*, *Castanea*, *Juglans*, *Alnus*, *Pterocarya*, *Rhus*, *Carya*, *Ginkgo*, and *Magnolia*. Some elements of *Elaeagnaceae* were scattered in the foothills. The undergrowth included herbs of *Plum-*



baginaceae, Primulaceae, Labiatae, Compositae, and others. The drought-resistant plants, *Ephedra* and chenopods, were widely distributed on the plain (Hsu, 1956).

Some forests of *Abies*, *Picea*, *Pinus*, *Cedrus*, *Betula*, and *Quercus* lived on the hills around the Quidam Basin. Trees of Magnoliaceae and Proteaceae grew scattered in the valleys. The undergrowth included herbs of Compositae, Cruciferae, Gramineae, and others (Hsü et al., 1958).

In western Gansu, pine forests were better developed in the hills around the Jiuquan Basin. *Magnolia* and *Ginkgo* grew on hilly tracts. Drought-resistant *Ephedra* was widely distributed on the plain (Song, 1958).

#### WARM-TEMPERATE TO SUBTROPICAL DECIDUOUS AND CONIFER FORESTS IN NORTHEASTERN CHINA AND NORTH CHINA

This flora was the successor of the Boreal Late Cretaceous mesophytic flora of northeastern China, the eastern part of Inner Mongolia, and North China. Although no Paleocene megafossils have so far been recorded in this area, a spore-pollen assemblage in Fushun (123.9°E, 41.8°N) indicates that some mesophyllous forests flourished, in which *Sphagnum*, *Lycopodium*, *Sequoia*, *Metasequoia*, and *Ginkgo* were present. Of the angiosperms, Ulmaceae, Juglandaceae, Betulaceae, and Myricaceae were predominant. This flora was also composed of *Pinus*, *Picea*, *Abies*, *Cedrus*, *Quercus*, *Ulmus*, *Salix*, *Buxus*, *Liquidambar*, *Cornus*, and *Magnolia*. The general aspect of this flora was very similar to those of the same age found in East Siberian and Sakhalin Island (Song & Liu, 1976; Sun, Du & Sun, 1980).

By the late Eocene, *Osmunda*, *Lygodium*, *Salvinia*, *Ginkgo*, *Metasequoia*, *Sequoia*, *Glyptostrobus*, *Torreya*, *Taxodium*, *Keteleeria*, *Pinus*, *Populus*, *Comptonia*, *Alnus*, *Betula*, *Corylus*, *Carpinus*, *Fagus*, *Dryophyllum*, *Quercus*, *Zelkova*, *Celtis*, *Nelumbo*, *Trochodendron*, *Cercidiphyllum*, *Schisandra*, *Cinnamomum*, *Lindera*, *Hydrangea*, *Hamamelites*, *Fothergilla*, *Exocarpos*, *Rosa*, *Acacia*, *Mimosites*, *Phellodendron*, *Ailanthus*, *Rhus*, *Acer*, *Koelreuteria*, *Meliosma*, *Paliurus*, *Rhamnus*, *Zizyphus*, *Ampelopsis*, *Firmiana*, *Fraxinus*, *Viburnum*, *Sparganium*, and *Sabalites* existed in Fushun (Fig. 2:2). Fagaceae, Betulaceae, Ulmaceae, Rosaceae, and Rhamnaceae were most abundant. Most of them are

deciduous, except *Dryophyllum*, *Cinnamomum*, and *Sabalites*. Most genera are subtropical to warm temperate, but *Osmunda*, *Ginkgo*, *Metasequoia*, *Sequoia*, *Glyptostrobus*, *Torreya*, *Taxodium*, *Keteleeria*, *Dryophyllum*, *Meliosma*, and *Firmiana* are almost subtropical, and *Lygodium*, *Cinnamomum*, *Acacia*, and *Meliosma* are chiefly tropical.

In this flora, one-fourth of the species, such as *Osmunda lignitum*, *Alnus corylina*, *Betula populoides*, *Celtis preacuminata*, *Dryophyllum safordii*, *Lindera antique*, *Hamamelites inaequalis*, *Rosa hilliae*, *Acacia aquilonia*, *Mimosites variabilis*, *Ampelopsis acerifolia*, *Fraxinus rupinarum*, *Viburnum speciosum*, *Sparganium antiquum*, *Ginkgo adiantoides*, *Glyptostrobus europaeus*, and *Nelumbo protolutea*, as judged from the illustrations, seem similar to the Paleocene-Eocene plants of North America. Similarly, more than one-fourth of the species appear to be similar to European, Central Asian, and Siberian plants. These include *Osmunda lignitum*, *Lygodium kaulfussii*, *Ginkgo adiantoides*, *Glyptostrobus europaeus*, *Metasequoia disticha*, *Taxodium tinajorum*, *Alnus schmahausenii*, *Betula subpubescens*, *Dryophyllum dewalquei*, *Zelkova ungeri*, *Cercidiphyllum arcticum*, *Lindera antiqua*, *Phellodendron grandifolium*, *Paliurus colombii*, *Rhamnus duensis*, *Fraxinus juglandina*, *F. rupinarum*, and *Viburnum nordenskiöldii*.

*Taxodium*, *Sequoia*, *Comptonia*, *Fothergilla*, and *Sabal* are extinct in China, but still live in North America. By this time *Metasequoia*, *Alangium*, *Trochodendron*, *Pterocarya*, *Platycarya*, *Zelkova*, *Cercidiphyllum*, *Cinnamomum*, *Koelreuteria*, and *Paliurus* existed in both northeastern China and North America. They now occur only in eastern Asia.

Middle Eocene microfossils in the coastal region of Bohai also show that the climate of North China was warm temperate, characterized by a predominance of Taxodiaceae, Betulaceae, Juglandaceae, Ulmaceae, Sapindaceae, and also *Alangium*, *Platycarya*, *Lygodium* and *Osmunda*. By late Eocene-early Oligocene, *Ephedra* and *Schizaea* were abundant there. During the middle Oligocene, *Quercus*, *Ulmus*, *Alnus*, *Salix*, and *Melia* became dominant, and, in the late Oligocene, Ulmaceae and Juglandaceae became predominant.

As a whole, the Paleogene flora of North China was composed of *Abies*, *Larix*, *Picea*, *Cedrus*, *Keteleeria*, *Pinus*, *Tsuga*, *Carya*, *Engelhardia*,



*Platycarya*, *Pterocarya*, *Alnus*, *Betula*, *Carpinus*, *Fagus*, *Quercus*, *Ulmus*, *Celtis*, *Trochodendron*, *Nelumbo*, *Magnolia*, *Liquidambar*, *Melia*, *Elaeagnus*, *Tilia*, *Rhamnus*, *Nyssa*, *Cornus*, *Aralia*, *Symplocos*, *Fraxinus*, and *Lonicera*, associated with some elements of Liliaceae, Chenopodiaceae, and Compositae.

DRY CLIMATE FLORA WITH SCATTERED FORESTS  
IN THE SUBTROPICAL ZONE  
OF CENTRAL CHINA

Judged from a Paleocene sporo-pollen assemblage found in Jiangxi (Sun & He, 1980), the flora was composed chiefly of Schizaeaceae, Pteridaceae, Ulmaceae, Fagaceae, Lauraceae, Moraceae, Sapindaceae, Santalaceae, Magnoliaceae, Nysaceae, Symplocaceae, Hamamelidaceae, and the tropical families Rutaceae, Anacardiaceae, Proteaceae, Araliaceae, Sapotaceae, Meliaceae, Bignonaceae, Olacaceae, and Palmae. The genera *Schizaea*, *Pteris*, *Ephedra*, *Ulmus*, *Hemiptelea*, and *Quercus* were most abundant, followed by *Corylus*, *Sorbaria*, *Lespedeza*, *Rosa*, Chenopodiaceae, Cruciferae, Leguminosae, Polygalaceae, and Lythraceae.

Up to the Eocene, *Quercus*, *Xylosma* (Flacourtiaceae), Anacardiaceae, Hamamelidaceae, Myrtaceae, Symplocaceae, Nyssaceae, Santalaceae, Sapotaceae, and Olacaceae were very abundant. The temperate elements *Betula* and *Juglans* were less abundant.

The sporo-pollen assemblages of Hunan and Hubei of the same ages were similar to those of Jiangxi as described above.

By the late Eocene, megafossils of *Cinnamomum* cf. *lanceolatum* Heer and *Comptonia andersonii* Florin were recorded in Hunan (Sze & Lee, 1954). Some megafossils of the form genus *Palibinia* have been found in Shānxi, Henan, and Hunan (Tao, 1965; Li, 1965; Liu & Kong, 1978) (Fig. 2:3). The narrowness and coriaceous texture of the leaves indicate drier sites. Associated with these in Henan are leaves of *Ulmus*, *Fraxinus*, *Sophora*, *Crataegus*, *Campylotropis*, *Lespedeza*, *Cercidiphyllum*, *Zelkova*, *Dalbergia*, *Zanthoxylum*, and pollen of *Ephedra*, *Carpinus*, Myricaceae, Taxodiaceae, Cruciferae, and Leguminosae (Liu & Kong, 1973). *Palibinia* has been found in Bembridge, Isle of Wight, England, and Turkmenia of the same age. Evidently this flora was closely connected with the subtropical Tethyan Tertiary region of southwestern Asia and south Europe.

DECIDUOUS AND EVERGREEN FORESTS WITH  
CONIFEROUS FORESTS IN THE SUBTROPICAL  
ZONE OF COASTAL REGION  
OF EAST CHINA

This flora covered the coastal region of Jiangsu, Zhejiang, and Fujian provinces. As mentioned above, during this period mountains arose parallel to the coast line. By Paleocene-Eocene time, some deciduous and evergreen forests chiefly of Ulmaceae (*Ulmus*, *Zelkova*, *Aphananthe*, *Celtis*, *Trema*, and *Ostrya*), Betulaceae (*Carpinus*, *Alnus*, *Corylus*), Juglandaceae (*Carya*, *Pterocarya*, *Juglans*), and Fagaceae (*Fagus*, *Quercus*) associated with Taxodiaceae and Pinaceae (*Pinus*, *Keteleeria*, *Cedrus*, *Picea*, *Abies*) forest flourished in these mountains. Some tropical elements of *Abelia*, *Rhus*, Proteaceae, Magnoliaceae, and Olacaceae were present, as judged from palynological records (Wang et al., 1979; Song et al., 1981; Petroleum Geological Exploration Team of Xijiang, 1979) (Fig. 2:4).

Up to the Oligocene, forests of Ulmaceae, Fagaceae, and Meliaceae were abundant. In this flora there were some elements of Magnoliaceae, Juglandaceae, Myrtaceae, Rubiaceae, Moraceae, Araliaceae, Betulaceae, Oleaceae, Euphorbiaceae, and Rosaceae associated with *Tilia*, *Rhus*, and others. By this time, herbaceous plants, such as *Convolvulus*, *Gentiana*, *Hedyotis*, and Compositae, were present. Among the gymnosperms, Taxodiaceae became better developed than the pinaceous plants. *Ephedra* and *Schizaea* have been recorded, though not abundant. This indicates that this flora was more humid than that of Central China (Wang et al., 1979).

DECIDUOUS AND EVERGREEN FORESTS MIXED  
WITH CONIFEROUS FORESTS IN THE  
SUBTROPICAL ZONE AND MANGROVE VEGETATION  
ALONG THE SHORE OF THE SOUTH CHINA SEA

This area covered most parts of South China, including Guangxi and Guangdong and islands of the South China Sea. By the Paleocene, the flora was composed of deciduous and evergreen forests mixed with some conifers. These forests were mainly composed of Ulmaceae, Loranaceae, and Sapotaceae.

During the Eocene, palms became abundant. Other predominant plants were Ulmaceae (*Ulmus*, *Celtis*), Rutaceae, Fagaceae (*Quercus*, *Castanea*), Juglandaceae (*Carya*, *Juglans*, *Pterocarya*), *Liquidambar*, *Alnus*, *Salix*, and some Taxodiaceae (Sun, 1982). Megafossils of *Rhus*



(Schenk, 1883), *Osmunda*, *Lygodium*, *Palibinia*, *Cinnamomum*, *Nelumbo*, *Trapa*, *Nordenskioeldia*, *Goeppertia*, *Eucommia*, *Cyclocarya*, *Citrus*, *Ocotea*, *Dryophyllum*, *Nectandra*, and *Sabalites* (Guo, 1965) were recorded (Fig. 2:5).

Of the 18 species, one-third of them have been recorded from the Paleogene of North America, such as *Lygodium kaulfussii* Heer, *Osmunda lignitum* (Giebel) Stur, *Nelumbo protospeciosa* Saprota, *Nordenskioeldia borealis* Heer, and *Dryophyllum puryerensis* Berry. Others have been found in Europe, Kazakhstan, and Japan, such as *Palibinia laxifolia* Korovin, *Lygodium kaulfussii*, *Cinnamomum naitoanum* H. & T., *C. lartitii* Watelet, *Nelumbo protospeciosa*, and *Nordenskioeldia borealis*.

Up to the Oligocene, judged from palynological data, temperate elements, such as *Alnus*, *Betula*, *Juglans*, *Cedrus*, and *Ephedra*, became predominant and also included *Juglans*, *Quercus*, and the subtropical *Liquidambar*. The tropical *Caesalpinia* (Leguminosae) and the water fern *Ceratopteris* were well represented. Mangrove vegetation appeared along the Pacific coast. This flora was closely related to the Paleogene flora of Borneo. Many types of pollen are identical in each area, especially *Florschuetzia* (possibly pollen of *Sonneratia*).

#### SUBTROPICAL HIGHLAND FLORAS OF XIZANG, YUNNAN, AND GUIZHOU

Some fossils were recorded from the Xigaze Group of the Yarlung Zangbo valley (Guo, 1975) and the Qiuwu and the Menshi Series of the westernmost corner of Xizang (Geng & Tao, 1982) (Fig. 2:6), including Salicaceae (*Salix*, *Populus*), Moraceae (*Ficus*), Cercidiphyllaceae (*Cercidiphyllum*), Araliaceae (*Aralia*), Fagaceae (*Quercus*), Juglandaceae (*Juglandites*), Celastraceae (*Celastrus*), Leguminosae (*Cassia*, *Sophora*), Rhamnaceae (*Rhamnus*), Rosaceae (*Spiraea*), Marantaceae (*Phrynium*), Liliaceae (*Dianella*), Cyperaceae (*Cyperacites*), and Typhaceae (*Typha*). The age of these fossils was formerly assigned by the authors to the Late Cretaceous and Late Cretaceous to Eocene, respectively. After recent investigation by field geologists, both have been shown to belong to the Eocene (Yin, personal communication). Most of these genera now live in tropical regions. *Ficus* is pantropical. *Phrynium* is distributed in Indomalaysia and tropical Africa. *Dianella* is distributed in tropical Asia, Australia, New Zealand, and Polynesia.

Of the 23 species, half of them, as judged from illustrations, seem similar to Paleogene plants of North America, such as *Populus latior* Al. Braun, *Salix meeki* Newberry, *Juglandites sinnatus* Lesquereux, *Ficus daphnogenoides* (Heer) Berry, *F. myrtifolia* Berry, *F. stephensoni* Berry, *Cercidiphyllum ellipticum* Brown, *Rhamnites eminens* Bell, *Viburnum asperum* Newberry, *Cassia fayettensis* Berry, *C. marshalensis* Berry, and *Celastrus minor* Berry. Others, such as *Salix viminalis* L. and *Spiraea alpina* Turq., resemble those of Europe and East Asia.

A tropical-subtropical Oligocene flora occurs in Jinggu, southern Yunnan. It is mainly composed of evergreen plants, Lauraceae (*Phoebe*, *Machilus* and *Nothophoebe*), and Fagaceae (*Lithocarpus*, *Quercus* and *Dryophyllum*). Others were of Annonaceae (*Annona*), Araliaceae (*Oreopanax*), Combretaceae (*Terminalia*), Moraceae (*Ficus*), Styracaceae (*Rehderodendron*), Leguminosae (*Cercis*, *Erythrophloeum*), and gymnosperms (*Cephalotaxus*, *Calocedrus*). Shrubs of *Rhus*, *Rosa*, *Jasminum*, and *Sorbus* were part of the understory. Similar specimens, such as *Zelkova ungeri*, *Myrica banksiaefolia*, and *Carya cordioides*, have been found in Europe and Central Asia, and *Oreopanax oxfordensis* and *Quercus simulata* have been recorded from North America.

#### NEOGENE VEGETATION IN CHINA

By Neogene time China was at a slightly higher latitude. Neogene taxa were more modern, the flora was more complex in composition, and herbaceous plants were better developed.

#### TEMPERATE-WARM TEMPERATE FORESTS AND GRASSLANDS AND DESERT-SEMIDESERT FLORA OF NORTHWESTERN CHINA

This flora was developed in Xinjiang, Qinghai, and Gansu, but later extended to eastern Inner Mongolia.

By the Miocene, due to decreased temperature, *Larix* and *Picea* forests began to develop in the Altai Mts., and the alpine *Sabina* forests covered mountains of northern Xinjiang. Deciduous forest composed of *Betula*, *Ulmus*, *Salix*, *Populus*, *Juglans*, *Alnus*, *Corylus*, and *Tilia* occurred in some foothills. Grasslands with *Artemisia*, *Ephedra*, and chenopods covered the plains. Most parts of the Talimu Basin were covered by grassland. Some trees of Taxodiaceae, Palmae, Myrtaceae, Lauraceae, Magnoliaceae, Anacardi-



aceae, Ulmaceae, *Quercus*, and *Juglans* were scattered in the foothills north of the Talimu Basin (Hsü & Li, 1980). Subalpine coniferous forests composed mainly of *Pinus*, *Cedrus*, *Abies*, *Tsuga*, and *Juniperus* were flourishing on the northern slope of the Kunlun Mts. (Hsü & Li, 1980). Deciduous forests of *Quercus*, *Castanea*, and *Alnus* occurred in the valleys. Grasslands of chenopods, Polygonaceae, and Cyperaceae, associated with *Ephedra*, covered the plains of the Quidam Basin and Gansu (Hsü et al., 1958). After the withdrawal of the Obé Sea from Central Asia, the Mediterranean elements Tamaricaceae and Zygophyllaceae (*Nitraria* and others), migrated through Central Asia to the Quidam Basin and Gansu (Li, 1960). In certain places salt marsh vegetation appeared (Fig. 3:1).

Active orogeny of the Himalayas and other mountains in Xizang caused the climate of northwestern China to become drier than before. The alpine forests of *Larix* and *Picea*, in addition to *Abies*, were better developed in the Altai Mts. Some pine forest mixed with *Betula*, *Ulmus*, *Quercus*, *Corylus*, and *Tilia* appeared in the foothills. But *Picea* forests were better developed in the Tianshan, western Kunlun, and Qilian Shan, with an understory of some *Rosa* and *Spiraea* shrubs (Hsü & Li, 1980). On the plains occurred a vegetation composed of drought-resistant *Tamarix*, *Nitraria*, *Ephedra*, *Artemisia*, Chenopodiaceae, Polygonaceae, and Gramineae. Deciduous forests of *Populus*, *Salix*, *Ulmus*, *Acer*, *Fraxinus*, and *Celtis* were scattered in some valleys (Hsü & Li, 1980).

#### WARM TEMPERATE TO SUBTROPICAL DECIDUOUS FORESTS AND GRASSLANDS OF NORTHEASTERN AND NORTH CHINA

Palynological investigation shows that at the beginning of the Neogene forests of *Picea*, *Pinus*, *Carya*, *Fagus*, *Quercus*, *Alnus*, and *Celtis* were distributed in the Sanjiang Plain (126 to 128°E, 46 to 48°N) of northeastern China. Later, forests of *Abies*, *Picea*, *Betula*, and *Pinus* became dominant due to decreased temperature (Li, 1982).

By this time, some mesophyllous forests appeared in Shanxi and Hebei, composed mainly of Pinaceae, Betulaceae, Fagaceae, Ulmaceae, Juglandaceae, and Rosaceae. Among them some thermophilous elements such as *Carya*, *Liquidambar*, and *Corylopsis* were present (Li, 1982).

The late Miocene flora of Shandong (Fig. 3:2)

is well represented by the Shanwang flora (Hu & Chaney, 1940; Inst. Bot. and Inst. Geol. and Paleont., 1978). It was mainly composed of deciduous trees and shrubs associated with some evergreen elements. The flora includes Fagaceae (*Castanea*, *Castanopsis*, *Quercus*), Betulaceae (*Alnus*, *Betula*, *Carpinus*, *Corylus*), Juglandaceae (*Carya*, *Platycarya*, *Juglans*), Ulmaceae (*Ulmus*, *Celtis*, *Zelkova*), Salicaceae (*Populus*, *Salix*), Moraceae (*Broussonetia*), Hamamelidaceae (*Fothergilla*, *Hamamelis*, *Liquidambar*), Rosaceae (*Crataegus*, *Eriobotrya*, *Malus*, *Prunus*, *Rosa*, *Spiraea*), Aceraceae (*Acer*), Anacardiaceae (*Rhus*, *Pistacia*), Sapindaceae (*Aesculus*, *Koeleruteria*), Saxifragaceae (*Hydrangea*), Leguminosae (*Albizia*, *Cercis*, *Gleditsia*, *Gymnocladus*, *Pueraria*, *Sophora*), Celastraceae (*Celastrus*, *Euonymus*), Rhamnaceae (*Berchemia*, *Hovenia*, *Paliurus*, *Ziziphus*), Tiliaceae (*Tilia*), Cornaceae (*Cornus*), Ebenaceae (*Diospyros*), Bignoniaceae (*Catalpa*), Vitaceae (*Ampelopsis*), and Simarubaceae (*Ailanthus*), plus some subtropical plants of Araliaceae (*Kalopanax*), Magnoliaceae (*Magnolia*), Lauraceae (*Lindera*, *Litsea*, *Cinnamomum*), Rutaceae (*Evodia*), Euphorbiaceae (*Mallotus*), Ulmaceae (*Aphananthe*), and tropical plants of Sterculiaceae (*Commersonia*), Moraceae (*Ficus*), and Vitaceae (*Tetrastigma*).

This flora consists of 125 species, of which five, *Corylus macquarrii*, *Juglans acuminata*, *Salix angusta*, *Astronium truncatum*, and *Fraxinus dayana*, seem similar to those of North America. Ten species, *Amelanchier sibirica*, *Podogonium ochningense*, *Acer subpictum*, *Vitis romanetii*, *Viburnum nordenskiöldii*, *Corylus macquarrii*, *Juglans acuminata*, *Populus glandulifera*, *Salix argusta*, and *Astronium truncatum*, seem common to those of Europe, Central Asia, and Siberia. It is interesting to note that *Fothergilla* existed there, but is not now in China.

According to palynological investigation, *Ulmus* was quite dominant in this flora, and *Metasequoia*, *Sequoia*, *Glyptostrobus*, and *Pinus* also lived there (Song et al., 1964), though the conifers are not recorded as megafossils.

Up to the time of the Pliocene, judged from palynological investigations, coniferous forests of *Abies*, *Picea*, and *Pinus* existed in the western part of North China. Mixed forests of *Ginkgo*, *Cryptomeria*, *Pinus*, *Betula*, *Salix*, *Alnus*, *Quercus*, *Ulmus*, *Zelkova*, *Fraxinus*, and *Celtis* were flourishing, but many tropical trees were no longer present. Megafossils found in Taigu, Shansi,



were composed mainly of *Quercus*, *Ulmus*, *Acer*, *Amelanchier*, *Ribes*, and Leguminosae, all of which are native plants now. No taxa are known to be identical with those of North America.

#### SUBTROPICAL EVERGREEN AND DECIDUOUS FORESTS OF CENTRAL AND EAST CHINA

During the Miocene, the vegetation of Central and East China turned into coniferous and evergreen and deciduous forests in sharp contrast to those of the Paleogene. Forests of *Pinus*, *Keteleeria*, *Cedrus*, *Carya*, *Castanea*, *Quercus*, *Ulmus*, *Liquidambar*, and *Tilia* were better developed. Judged from palynological records, the coniferous forests of East China were mainly composed of *Pinus*, *Abies*, *Tsuga*, *Picea*, *Keteleeria*, and *Cedrus*. Deciduous forests were mainly composed of Ulmaceae (*Ulmus*, *Celtis*, *Zelkova*), Juglandaceae (*Carya*, *Juglans*, *Pterocarya*), Betulaceae (*Betula*, *Alnus*, *Corylus*), Fagaceae (*Quercus*, *Fagus*, *Castanea*), Hamamelidaceae (*Liquidambar*, *Fothergilla*, *Corylopsis*), and Myricaceae (*Myrica*), mixed with some evergreen trees like *Magnolia*, *Quercus*, *Symplocos*, etc. *Carya*, *Pterocarya*, *Sapindus*, *Ilex*, *Symplocos*, *Corylopsis*, *Pittosporum*, *Melia*, *Liquidambar* and some elements of Rutaceae, Euphorbiaceae, Myrtaceae, and Olacaceae existed there, representing a flora of subtropical nature. Herbaceous plants were quite abundant, mainly composed of Umbelliferae, Convolvulaceae, Cruciferae, Cyperaceae, and Gramineae (Guan et al., 1979; Song et al., 1981; Zheng et al., 1981) (Fig. 3:3).

During the Pliocene, herbaceous plants became dominant. Much pollen of Compositae (*Artemisia*, *Blumea*, *Dichrocephala*, *Bidens*, *Coreopsis*, *Ixeris*, and others), Amaranthaceae, Caryophyllaceae, and Chenopodiaceae have been recorded. Pollinia of Orchidaceae also appeared. Judged from palynological records, the coniferous forests were evidently reduced. Deciduous forests became dominant and were composed chiefly of *Ulmus*, *Celtis*, and *Quercus*. It is worth noting that the tropical *Caesalpinia*, *Nyssa*, *Buxus*, orchids, and some Annonaceae and Euphorbiaceae are occasionally recorded. Salt marsh vegetation existed in the coastal region (Zheng et al., 1981).

By this time, the flora of western Sichuan was composed mainly of *Castanopsis*, *Quercus*, and *Actinodaphne*, associated with some *Acer* and *Sorbus* (Guo, 1978).

#### SUBTROPICAL EVERGREEN FORESTS AND TROPICAL MANGROVE VEGETATION IN SOUTH CHINA

During the Miocene, forests of this region were composed mainly of *Castanopsis*, *Quercus*, *Lithocarpus*, *Juglans*, *Castanea*, *Carya*, *Pterocarya*, Moraceae, Palmae, and Hamamelidaceae. In the coastal region a vegetation rich in chenopods existed. A mangrove vegetation of *Sonneratia* appeared along the coast (Sun et al., 1981) (Fig. 3:4).

#### SUBTROPICAL EVERGREEN AND DECIDUOUS FORESTS ON THE YUNNAN AND XIZANG PLATEAU

By the Miocene, the vegetation of southern Yunnan was composed of Cupressaceae (*Calocedrus*), Aceraceae (*Acer*), Alangiaceae (*Alangium*), Lauraceae (*Laurus*, *Cinnamomum*), Leguminosae (*Albizia*, *Cassia*, *Dalbergia*, *Desmodium*, *Sophora*, and *Pithecelobium*), Juglandaceae (*Pterocarya*), Fagaceae (*Castanea*, *Quercus*), Hamamelidaceae (*Distylium*, *Simi-notonia*), and Rhamnaceae (*Rhamnella*). This flora was closely related to a flora of similar age in Vietnam (Inst. Bot. and Inst. Geol. and Palaeont., 1978).

The Miocene flora of northern Yunnan included *Pinus*, *Cupressus*, Fagaceae (*Dryophyllum*, *Quercus*), Lauraceae (*Sassafras*, *Phoebe*, *Cinnamomum*), Ulmaceae (*Zelkova*), Anacardiaceae (*Rhus*, *Pistacia*), and Rhamnaceae (*Pal-iurus*) (Fig. 3:5).

By the Pliocene an evergreen forest mixed with conifers appeared. The chief elements were the sclerophyllous *Quercus semecarpifolia*, *spathulata*, *pannosa*, *monimothicha*, and *gilliana*. Others were *Acer paxii*, *Celtis bungeana*, *Viburnum ovalifolium*, *Betula*, *Populus*, *Ulmus*, *Michelia*, and *Rhododendron*, associated with some Rosaceae and Leguminosae. Conifers were dominant, including *Pinus yunnanensis*, *Cedrus deodara*, *Picea*, *Larix*, and *Tsuga*. *Pinus yunnanensis* was very abundant there, but *Cedrus deodara* had migrated to the southwestern part of the Himalayas (Tao & Kong, 1973).

During this time, the forests of northwestern Yunnan were composed mainly of Fagaceae, Lauraceae, Leguminosae, Theaceae, and Loganiaceae. About half of the plants are identical to the recent ones. Most of them belong to *Castanopsis*, *Ulmus*, *Eurya*, and *Strychnos*. In addi-



tion, many species of Rhamnaceae, Fagaceae, Anacardiaceae, Leguminosae, Rosaceae, Alangiaceae, Lauraceae, and Myricaceae also occupied the southern slope of the Himalayas. This suggests that during the Neogene there was an extensive migration of plants between Xizang and Yunnan and the northern part of the South Asian subcontinent (Tao & Du, 1982) (Fig. 3:5).

By the Miocene, vegetation of central Xizang was composed mainly of *Juglans*, *Sophora*, *Populus*, *Betula*, *Carpinus*, *Ulmus*, *Ribes*, *Crataegus*, *Quercus*, *Thermopsis*, *Rhododendron*, *Salix*, *Cedrus*, *Tsuga*, *Sabina*, and *Podocarpus*. Similar vegetation was flourishing in the western Xizang (Hsü, 1981) (Fig. 3:5).

Passing to the early Pliocene, forests of *Abies*, *Picea*, *Tsuga*, *Cedrus*, *Lithocarpus*, *Quercus*, *Fagus*, *Salix*, *Carya*, *Melia*, and *Ilex* were widespread in northern Xizang. It is interesting to note that pollen of some tropical elements, such as *Podocarpus* and Araliaceae and spores of the epiphytic fern *Drynaria*, were found at some sites.

Up to the late Pliocene some subalpine forests were widespread on the northern slope of the Himalayas. *Cedrus deodara* and some sclerophyllous evergreen oaks, *Quercus semecarpifolia*, *pannosa*, and *senescens*, were predominant. The general aspect of the flora and the floral composition were much like those of the Pliocene flora of northern Yunnan (Xu, 1981).

#### QUATERNARY VEGETATION IN CHINA

The Quaternary vegetation in China did not differ very much from that of the late Pliocene. However, there were some evident changes, since the evolution of plants was rapidly progressing. The change of vegetation during this period was mainly caused by the effects of decreasing and oscillating temperature, lowering and rising of sea level, and variance in topography, especially the uplift of the Qinghai-Xizang Plateau, the Himalayas, and other mountains.

#### APPEARANCE OF A COLD TEMPERATE FOREST ZONE IN THE NORTHERNMOST CHINA

From the late Pliocene up to the late Pleistocene, some Siberian, cold-temperate taxa penetrated southward 4° to 5° to form taiga in northern Xinjiang and northern Heilungjiang. Forests of *Larix gmelini* migrated southward to-and-fro several times from the Altai Mts. This forest passed along the Beitashan Range, was widely distributed in the Dzungarian Basin, and intruded the east end of the Tianshan Range (Chang,

1959). Forests of *Larix gmelini* also migrated southward several times as far as the Sanjiang plain (Kong & Du, 1982). By the time of the Late-Glacial, *Abies-Picea* forests associated with *Betula* were developed on the plain, leaving the taiga forests flourishing in the Taixinanling and the Xianxianling Mts. (Fig. 4:1).

#### SHIFTING OF THE SOUTHERN BOUNDARY OF THE WARM-TEMPERATE, DECIDUOUS-FOREST ZONE

The southern boundary of the warm-temperate zone shifted southward 3° to 5° during the Quaternary Period. Although the Qinling Range is an old mountain range running from west to east, across China, it was not high enough to separate climates in eastern China in the early Pleistocene. The palynological record shows that the subtropical plants *Ginkgo*, *Podocarpus*, *Cedrus*, *Tsuga*, *Pseudolarix*, *Cunninghamia*, *Pterocarya*, *Platycarya*, *Carya*, and *Magnolia* still resided in Shānxī (=Shenxi), north of the Qinling Mts. (Inst. Bot. and Inst. Geol., 1966). Only after the middle Pleistocene, were the Qinling Mts. uplifted to the present altitude, thus forming a barrier to prevent seasonal winds from the south passing over to North China. Since then, the climate of North China has become drier and cooler, and the Qinling Mts. have begun to act as a barrier between the subtropical and the warm-temperate zones of Eastern China. Accordingly, the previously mentioned subtropical plants no longer lived in North China (Fig. 4:2).

#### EXTENSION OF THE DRY-CLIMATE ZONE OF NORTHWESTERN CHINA TO NORTH CHINA

By the early Pleistocene the semiarid zone was limited to northwestern China. Some basins in eastern Qinhai were still covered by grasslands. Only coniferous forests of *Cedrus*, *Picea*, and *Pinus* and deciduous forests of *Juglans*, *Quercus*, *Populus*, and *Salix* flourished in the hills. Up to the middle Pleistocene, the dry-climate zone extended westward to North China. Then the coniferous forests were mainly composed of *Pinus* and *Picea*. *Cedrus* no longer existed in this portion of Qinhai. *Alnus* and *Populus* were the chief components in the deciduous forests. Up to the late Pleistocene, due to the effect of desiccation, the size of forests and grasslands were much reduced. Some grasslands became semidesert (Fig. 4:3).

In North China some forests of conifers and broad-leaved trees still flourished in the early Pleistocene. Grasslands were well developed into



the middle Pleistocene. During the late Pleistocene, deciduous forests and grasslands were much reduced, and their composition became simpler. The forests were composed mainly of *Ulmus*, *Celtis*, *Morus*, *Quercus*, and *Populus*. By this time herbaceous plants were rich in Gramineae, Chenopodiaceae, Cruciferae, and Compositae (Inst. of Botany and Inst. of Geology and Palaeontology, 1978).

#### CHANGE OF VEGETATION DUE TO OSCILLATION OF TEMPERATURE

During the Pleistocene there may have been as many as 17 glaciations (Heller & Liu, 1982). Due to oscillation of temperature during that time, *Abies-Picea* forests were better developed in the eastern part of China, but during interglacial periods the forests decreased in area. Fagaceae was the most common group in the subtropical and moist zone, while Ulmaceae was the dominant one in the warm-temperate and drier regions.

During the last glacial (Wisconsinian) period *Abies-Picea* forests were better developed on the northern slope of the Qinling Range. *Picea wilsonii* forest once extended down to the hilly lands of 490 m in Weinan (109.5°E, 34.5°N) of Shānxi (Fig. 4:4), but is widely distributed in the hills of Hebei, Shanxi, Shānxi and northern Sichuan at an altitude of 1,600 to 2,500 m. *Abies* and *Picea* forests once flourished in the foothills around Beijing 430 to 450 m (Kong, 1976), but now these forests occur only above 1,600 to 2,000 m in this area. Fossils of *Picea* have been found in Panxian (104.7°E, 25.8°N) of western Guizhou at an altitude of 1,000 to 2,000 m, but this spruce now lives at an altitude of 2,200 to 2,400 m in northern Guizhou. By this time *Abies-Picea* forests were also widely distributed in East China. Now only a few trees of *Abies* survive as relicts in the hills of Zeijiang and northern Guangxi (Fig. 4:4).

#### VEGETATIONAL CHANGES DURING THE QUATERNARY IN THE XIZANG PLATEAU

During the early Pleistocene, the Xizang Plateau was about 3,000 m in elevation. Subalpine forests of *Cedrus*, *Pinus*, *Betula*, *Quercus*, *Carpinus*, and *Alnus* were widespread in the central Himalayas, while subalpine forests of *Larix*, *Abies*, *Picea*, *Pinus*, and *Sabina* flourished in western and northern Xizang, and subalpine forests of *Picea* and *Sabina* occurred in northern Xizang. By that time, the xerophilous plants *Ta-*

*marix* and *Nitraria* had already migrated from the Qinghai Plateau to northern Xizang (Fig. 4:5).

During the middle Pleistocene, the Xizang Plateau was uplifted to 3,500 m in altitude. Subalpine forests of *Picea*, *Cedrus*, *Sabina* and sclerophyllous evergreen *Quercus semecarpifolia*, *pannosa*, and *senescens* were widely distributed in the central Himalayas. But subalpine forests of *Pinus*, *Betula*, *Quercus*, *Carpinus*, and *Alnus* still occurred there. Due to decreased temperature and rainfall only few forests could survive in northern Xizang, so xerophytic plants *Ephedra*, *Tamarix*, *Nitraria*, *Artemisia*, and chenopods were better developed there.

As the result of uplift, as the Xizang Plateau rose to 4,000 m, few forests could survive in northern Xizang.

Passing to the Post Glacial, the altitude of the Xizang Plateau was 4,500 m in elevation, and the vegetation of most parts of Xizang became alpine steppes.

#### ACCELERATION OF EVOLUTION DUE TO TOPOGRAPHIC AND CLIMATIC CHANGES

The speed of evolution of the angiosperms of Xizang was accelerated by the uplift of the Xizang Plateau. Plants in Xizang adjusted to the influences of topographic and climatic changes by evolving some new genera and species. More than 32 new genera of Umbelliferae, Primulaceae, Solanaceae, Compositae, and Gramineae have recently been discovered in Xizang (Wu et al., 1981). Most of the species of Gramineae are polyploids (Liu, personal communication). At the same time, a new regional alpine flora was formed (Wu et al., 1981) (Fig. 4:6).

#### MIGRATION OF PLANTS BETWEEN MAINLAND OF CHINA AND THE ADJACENT ISLANDS

Lowering of sea levels caused by the withdrawal of ocean water to form the Pleistocene ice sheets caused the Pacific coast to extend eastward to the Taiwan-Ryukyu Area-Kyushu during the glacial periods. This enabled some plants from Fujian to migrate directly to Taiwan and from Guangdong to Hainan, and *vice versa* (Fig. 4:7).

#### THE RELATIONSHIP OF CHINESE PAST FLORAS WITH THOSE OF NORTH AMERICA

Paleobotanical records previously mentioned tell us that most of the Late Cretaceous and Paleocene-Eocene plants were widely distributed in



Laurasia. During the Late Cretaceous less than one-third appear to be similar to European, Central Asian, and Siberian species and one-half to two-thirds appear similar to North American species. By the time of Paleocene-Eocene, one-third to one-fourth of the species seem similar to those of Europe, Central Asia, and Siberia, and one-fourth to one-half seem similar to those of North America. This reflects an extensive migration between the Chinese and North American floras via Central and West Asia and Europe before the middle Eocene, as there were no effective barriers such as ocean or high mountains in these regions. By this time there was also no land bridge available in the Bering region for migration of plants between Asia and North America.

By the Oligocene most species in China were of eastern Asiatic origin. One-tenth were common with the plants of Europe and Central Asia and less than one-tenth appear to be similar to those of North America. Until the Miocene about one-tenth of the plants recorded in China were common with the European, Central Asian, and Siberian species, and only one-twenty-fifth seem similar to the North American species. Up to the Pliocene, most of the Chinese plants were of eastern Asiatic origin, only a few were common with European, Central Asian, and Siberian species, and very few appear to be similar to North American species. This means that after the Eocene Chinese vegetation was rapidly modernized by a loss of the American elements. Some Chinese Oligocene and Miocene species common with those of North America are remnants of mesophytic plants once widely distributed over all the northern hemisphere.

I agree with the view of Li (1971) that most of the present isolated and disjunct genera of eastern Asia, especially of China, and eastern North America are the remnants of ancient plants widely distributed all over the northern hemisphere. I also agree with the view that the present disjunction of genera is mainly due to "Tertiary and Pleistocene extinction, except the local areas with persistence of favorable climatic conditions" as claimed by Schuster (1976).

At present, eastern North America and eastern Asia (especially the southern part of China) are two important relict temperate centers in the northern hemisphere, because in both regions there were no extensive Pleistocene glaciations, and they both have more favorable climatic conditions. However, of these two regions, eastern

Asia (especially southern China) has more relict genera than eastern North America.

#### LITERATURE CITED

- ANTEVS, E. 1928. The last glaciation. New York, Amer. Geogr. Soc., Research Series 17.
- AXELROD, D. I. 1952. A theory of angiosperm evolution. *Evolution* 4: 29-60.
- BERRY, E. W. 1937. Tertiary floras of Eastern North America. *Bot. Rev. (Lancaster)* 3: 31-46.
- BROOKS, C. E. P. 1950. *Climate Through the Ages*. Ernest Benn Co., London.
- CHANG, SINSHI. 1959. Geographical distribution of the eastern Tianshan forest. Papers on the Symposium of the Natural Factors in the Sinjiang Autonomous Weiwoer Region. Science Press, Beijing. (In Chinese.)
- DEFFEYES, KENNETH S. 1973. Earth's heat engines. *Science Year* 1973: 163-176.
- DIETZ, R. S. & J. C. HOLDEN. 1970. Reconstruction of Pangea: Break up and dispersion of continents, Permian to present. *J. Geophys. Res.* 75: 4939-4956.
- DREWRY, G. E., A. T. S. RAMSAY & A. G. SMITH. 1974. Climatically controlled sediments, the geomagnetic field, and trade wind belts in Phanerozoic time. *J. Geol.* 82: 531-553.
- FLORIN, RUDOLF. 1958. On Jurassic taxads and conifers from northwestern Europe and eastern Greenland. *Acta Horti Berg.* 17: 257-402.
- . 1963. The distribution of conifers and taxad genera in time and space. *Acta Horti Berg.* 20: 121-312.
- FRAKES, L. A. & E. M. KEMP. 1972. Influence of continental position on early Tertiary climate. *Nature* 1972, Nov. 10: 97-100.
- GENG, GUOCANG & TAO JUNRONG. 1982. Tertiary plants from Tibet. Scientific Expedition to Qinghai-Xizang Plateau. *Palaeontology of Xizang*, V: 110-125. Science Press, Beijing. (In Chinese with English summary.)
- GOOD, R. 1947. *The Geography of the Flowering Plants*. Longmans, Green & Co.
- GORDON, W. A. 1973. Marine life and ocean surface currents in the Cretaceous. *J. Geol.* 81: 269-284.
- GRAY, A. 1846. Analogy between the flora of Japan and that of the United States. *Amer. J. Sci. Arts* II(2): 135-136.
- GUAN, XUETING, TIEN XIUMEI & SUN XINHUA. 1979. On sporo-pollen assemblages and palaeogeography of the Neogene of Bohai. Selected papers from the First Symposium of the Palynological Society of China. Pp. 64-70. Science Press, Beijing. (In Chinese.)
- GUO, SHUANGXING. 1965. On the discovery of fossil palms from the Tertiary formation of Kwangtung and Kwangsi. *Acta Palaeontol. Sin.* 13(4): 598-606.
- . 1975. The plant fossils of the Xigaze Group from Mount Jolmo Lungma Region. Reports of Scientific Expedition to the Mt. Jolmo Lungma Region. *Palaeontology*, Fasc. 1: 411-423. Science Press, Beijing. (In Chinese.)
- . 1978. Pliocene floras of western Sichuan. *Acta*



- Palaeontol. Sin. 17(3): 343–350. (In Chinese with English summary.)
- . 1979. Late Cretaceous and early Tertiary floras from the southern Guangdong and Guangxi with their stratigraphic significance. Mesozoic and Cenozoic red beds of South China. Pp. 223–231. Science Press, Beijing. (In Chinese.)
- & LI HAOMIN. 1979. Late Cretaceous flora from Huncian of Jilin. Acta Palaeontol. Sin. 18(6): 547–560. (In Chinese with English summary.)
- HELLER, F. & T.-S. LIU. 1982. Magnetostratigraphical dating of loess deposits in China. Nature 300: 431–433.
- HSÜ, JEN. 1956. Sporopollen assemblage from the Tertiary deposits of Talufan, Jiuquan and Quidam Basin and its geological significance. News letter of the Chinese Palaeontological Society 1. (In Chinese.)
- . 1978. On the paleobotanical evidence for continental drift and Himalayan uplift. Palaeobotanist 25: 131–142.
- , SONG TZECHEN & CHOW HOI. 1958. Sporopollen assemblages from the Tertiary deposits of the Tsaidam Basin and their geological significance. Acta Palaeontol. Sin. 6(4): 429–440. (In Chinese with English summary.)
- , ZHU JIANAN, CHEN YE, DUAN SHUYING, HU YUFAN & ZHU WEIQING. 1974. New genera and species of the late Triassic plants from Yungjen, Yunnan, I. Acta Bot. Sin. 16(3): 266–278. (In Chinese with English summary.)
- & LI SIYIN. 1980. Development and evolution of the Chinese Cenozoic vegetation. Pp. 65–76 in Wu et al., (editors), Vegetation of China, Chapter III. Science Press, Beijing. (In Chinese.)
- HU, H. H. & R. W. CHANEY. 1940. A Miocene flora from Shantung Province, China. Paleontologia Sinica, New Ser. A (1).
- INSTITUTE OF BOTANY, ACADEMIA SINICA & CENOZOIC PALYNOLOGICAL SECTION, INSTITUTE OF GEOLOGY, MINISTRY OF GEOLOGY. 1966. Researches in Cenozoic palaeobotany of Nantian, Shānxi. Proceedings of the Symposium on the Cenozoic researches of Nantian, Shānxi. Pp. 157–182. Science Press, Beijing. (In Chinese.)
- INSTITUTE OF BOTANY & INSTITUTE OF GEOLOGY AND PALEONTOLOGY, ACADEMIA SINICA. 1978. Cenozoic plants from China. Fossil plants of China 3. Science Press, Beijing. (In Chinese.)
- KONG, ZHAO-CHEN, DU NAIQIU, SHI YICHEN & TAO JINRONG. 1976. Vegetation and climatic changes during the past one hundred million years of Beijing. Acta Phytotax. Sin. 14(1): 82–89. (In Chinese with English summary.)
- & DU NAIQIU. 1982. The climate in Sanjiang Plain during the past 36,000 years (abstract). P. 172 in Quaternary Research Association of China: Quaternary Geology and Environment of China. China Ocean Press, Beijing.
- LI, HAOMIN. 1965. Rostitel'nyy ostatki paleogenovog rozrasta gorodka chashan po bosseyre khenyan. Acta Paleontol. Sin. 13(3): 540–547. (In Chinese and Russian.)
- LI, HUI-LIN. 1971. Floristic relationships between eastern Asia and eastern North America. Trans. Amer. Philos. Soc., New Ser. 42: 371–429. 1952. (A Morris Arboretum Monograph reprinted in 1971.)
- . 1972. Eastern Asia—eastern North America species-pairs in wide-ranging genera. Pp. 65–78 in A. Graham (editor), Floristics and Paleofloristics of Asia and Eastern North America. Elsevier Co., Amsterdam-London-New York.
- LI, SIYIN. 1960. Characteristic features of the vegetation on the northern side of the Kunlun Ranges. Its formation in relation to the arid region. Acta Bot. Sin. 9(1). (In Chinese.)
- LI, WENYI. 1982. Studies on vegetation and Palaeogeography from late Tertiary to early Quaternary in China. Pp. 109–112 in Quaternary Research Association of China: Quaternary geology and environment of China. China Ocean Press, Beijing.
- LIU, YONG-AN & KONG ZHAO-CHEN. 1978. Plant fossils of late Eocene from Wucheng, Henan and their significance in botany and palaeoclimatology. Acta Bot. Sin. 20: 59–65. (In Chinese with English summary.)
- MCELHINNY, M. W. 1970. Formation of the Indian Ocean. Nature 228: 977–979.
- PETROLEUM GEOLOGICAL EXPLORATION TEAM OF XIJIANG MARINE GEOLOGY DEPARTMENT OF TONGJI UNIVERSITY & THE LABORATORY OF THE THIRD MARINE GEOLOGICAL SURVEY. 1979. Sporopollen assemblage of Cretaceous-Tertiary of Xijiang. Science and Technology Report of Tongji University. (In Chinese.)
- PLANNING RESEARCH INSTITUTE OF PETROLEUM EXPLORATION AND DEVELOPMENT, MINISTRY OF PETROLEUM INDUSTRY & NANJIANG INSTITUTE OF GEOLOGY AND PALAEONTOLOGY, ACADEMIA SINICA. 1978. Early Tertiary spores and pollen grains from the coastal region of Bohai. Science Press, Beijing. (In Chinese with English summary.)
- RAVEN, P. H. & D. I. AXELROD. 1974. Angiosperm biogeography and past continental movements. Ann. Missouri Bot. Gard. 61: 539–673.
- SAITO, T. & J. VAN DONK. 1974. Oxygen and carbon isotope measurements of late Cretaceous and early Tertiary foraminifera. Micropaleontology 20: 152–177.
- SCHENK, A. 1883. Pflanzenreste aus dem Tertiär des südlichen China. In Richtofen's China. Bd. 4. S. 268.
- SCHUSTER, R. M. 1976. Plate tectonics and bearing on the geological origin and dispersal of angiosperms. Pp. 48–136 in Charles B. Beck (editor), Origin and Early Evolution of Angiosperms. Columbia Univ. Press.
- SCHWARZBACH, M. 1963. Climates of the Past—An Introduction to Paleoclimatology. (Translated and edited by R. O. Muir.) D. van Nostrand Co.
- SONG, ZHICHEN. 1958. Tertiary spore and pollen complexes from the red beds of Chiu-Chuan, Kansu, and their geological and botanical significance. Acta Palaeontol. Sin. 6(2): 159–167. (In Chinese with English summary.)
- & TSAO LIU. 1976. The Paleogene spores and pollen grains from the Fushun Coal Field, northeast China. Acta Palaeontol. Sin. 15(2): 147–162. (In Chinese with English summary.)
- , ——— & LI MANYING. 1964. Tertiary spo-



- ropollen complexes of Shantung. *Mem. Inst. Geol. Palaeontol. Acad. Sin.* 3: 179–190. (In Chinese.)
- , ZHENG YAHUI, LIU JINLING, YE PINGYI, WANG CONGFENG & ZHOU SHANFU. 1981. Cretaceous-Tertiary palynological assemblages from Jiangsu. Geological Publishing House, Beijing. (In Chinese.)
- SUN, XIANGJUN. 1982. Palynoflora of Liushegang Formation (Eocene-early Oligocene) in the northern part of South China Sea. *Acta Phytotax. Sin.* 20(1): 63–72. (In Chinese with English summary.)
- , DU NAIQIU & SUN MENGROG. 1980. Palynological investigation on the Fushun Group (Paleogene) of northeastern China. In Hong Youchong (editor), *Stratigraphy of the Fushun Coal Field, Liaoling and the fossil assemblages*. Science Press, Beijing. (In Chinese.)
- & HE YUEMING. 1980. Paleocene sporopollen assemblages of Jiangi. Science Press, Beijing. (In Chinese.)
- , KONG ZHAOCHEN & LI MINGXING. 1980. Paleogene new pollen genera and species of South China Sea. *Acta Bot. Sin.* 22(2): 191–199. (In Chinese with English summary.)
- , ———, LI PUN & LI MINGXING. 1981. Oligocene palynoflora in the northern part of South China Sea. *Acta Phytotax. Sin.* 19(2): 186–194. (In Chinese with English summary.)
- SZE, H. C. & LEE HOMER. 1954. A late Tertiary flora from Hunan. *Acta Sci. Sin.* 3(2): 205–218.
- TAKHTAJAN, A. 1969. *Flowering Plants, Origin and Dispersal*. Oliver and Boyd, Edinburgh. (English Translation by C. Jeffrey.)
- TAO, JUNRONG. 1965. A late Eocene florula from the district Weinan of central Shensi. *Acta Bot. Sin.* 13(3): 272–278. (In Chinese with English summary.)
- & KONG ZHAOCHEN. 1973. The fossil flora and sporopollen assemblage of the Shangin coal series of Erhyuan, Yunnan. *Acta Bot. Sin.* 15(1): 120–126. (In Chinese with English summary.)
- & DU NAIQIU. 1982. Neogene flora of Tengchong Basin in western Yunnan, China. *Acta Bot. Sin.* 24(3): 273–281. (In Chinese with English summary.)
- VAN DER LINDEN, W. J. M. 1975. Mesozoic and Cainozoic opening of the Labrador Sea, the North Atlantic and the Bay of Biscay. *Nature* 253: 320–324.
- WANG, XIANZENG, ZHOU SHANFU & XU SHUJUAN. 1979. Discussions on the palaeogeography and palaeoclimatology of the late Eocene epoch and Oligocene epoch, north Jiangsu. *Acta Bot. Sin.* 21(2): 149–156. (In Chinese with English abstract.)
- WU, ZHENGYI, TANG YANCHENG, LI XIWEN, WU SUGONG & HIHENG. 1981. Dissertations upon the origin, development and regionalization of Xizang flora through the floristic analysis. In Liu Dongsheng (editor), *Proceedings of Symposium on Qinghai-Xizang (Tibet) Plateau* (Beijing, China). Geological and ecological studies of Qinghai-Xizang Plateau, Vol. II. Pp. 1219–1244. Science Press, Beijing.
- WU, CHENGYI (WU ZHENGYI). On the significance of Pacific intercontinental discontinuity. In press.
- XU REN (HSÜ JEN). 1981. Vegetational changes in the past and the uplift of Qinghai-Xizang Plateau. In Liu Dongsheng (editor), *Proceedings of Symposium on Qinghai-Xizang (Tibet) Plateau* (Beijing, China). Geological and ecological studies of Qinghai-Xizang Plateau. Vol. I. Pp. 139–144.
- ZHENG, YAHUI, ZHOU SHANFU, LIU XIANGQI, WANG LIANYUAN, XU SHUJIAN & WANG XIANZHEN. 1981. Neogene sporo-pollen grains from northern Jiangsu and south Yellow Sea Basin. *Bull. Nanjiang Inst. Geol. and Palaeont., Academia Sinica* 1981 (3): 29–90. 15 pls. (In Chinese with English summary.)